Delayed Recognition of Geomorphology Papers in *The Geological Society of America Bulletin*

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Cite as:
Goldstein, E. B. (2017). Delayed recognition of geomorphology papers in the Geological Society of America Bulletin. *Progress in Physical Geography*, *41*(3), 363-368.
https://doi.org/10.1177/0309133317703093

Abstract

The *Geological Society of America Bulletin* was an early home for quantitative geomorphology research. Though geomorphology papers are not uniformly the highest cited papers in the *Bulletin*, many show 'delayed recognition' —they garner only few citations directly after publication, before suddenly being widely and numerously cited (sometimes decades after publication). I focus here on 1) algorithmically detecting cases of delayed recognition in geomorphology literature from the *Bulletin* and 2) providing insight into why delayed recognition occurred for these papers.

I. Introduction

The citation record of a paper is one measure of its impact and utility for other scientists. Most papers are typically cited heavily within several years of publication and once the initial window is closed, tend to be cited less frequently (e.g., Costas et al., 2010). This is not true for all papers however — some enjoy 'delayed recognition' in that they remain relatively uncited for long periods of time (even decades) before suddenly being 'rediscovered' and widely and numerously cited (e.g., Garfield, 1980). Finding and analyzing papers with delayed recognition (also referred to as 'sleeping beauties'; Van Raan, 2004) provides insight into a discipline — ideas that may have been 'ahead of their time'. Here I search for papers with delayed recognition that are published in *Geological Society of America Bulletin* (hereinafter, GSA Bulletin), an early venue for quantitative geomorphology (Morisawa, 1988). Nine of the top 20 papers with delayed recognition in GSA Bulletin concern geomorphology. After presenting these nine 'classic' papers and some general metrics, I discuss possible causes for delayed recognition.

II. Method of Search and Results

To look for papers with delayed recognition, I used the Web of Science to download citation histories for the 500 most cited papers published in GSA Bulletin in the 70 year record available (a record of ~7,000 'article' documents from 1945 to 2015). This search was performed on August 7, 2016. Note that all 500 'most cited' papers have each been cited more than 100 times. Using these 500 articles I apply the methodology of Ke et al. (2015) to estimate the delay recognition score (B) of each paper. In brief, B is calculated for a given paper by comparing the time series of citations per year to a reference line (L) that connects the year of publication to the maxima in the time series of citations per year (Figure 1). Larger values of B denote a stronger delay recognition signal — the yearly citation maxima occurring far from publication date and with fewer intervening citations. Additionally, a metric of 'awakening time' (t_a) can be calculated — defined as the year when a change in yearly citations is observed. This time is calculated by finding the point of maximum distance between the time series of citations per year and the reference line (L; Figure 1). These metrics are parameter free and do not rely on arbitrary, 'tuned' or discipline specific rules. Interested readers are encouraged to seek further details in Ke et al. (2015).

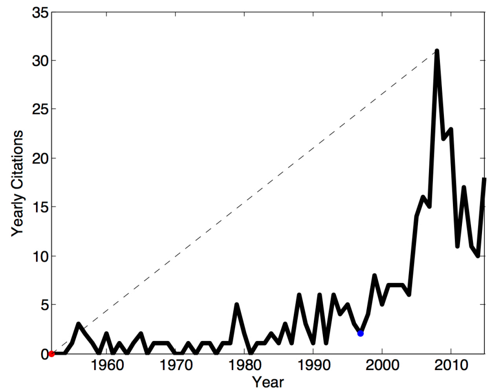

Figure 1: Definition sketch showing citation time series for Strahler (1952a; black line) with the date of publication (red dot). The reference line (L; dotted) is used to calculate the delayed recognition score (B). The awakening time (t_a; blue dot) is the point along the citation time series that is furthest from the L. Based on the work of Ke et al. (2015).

Of the top 20 delayed recognition articles from GSA Bulletin, nine are geomorphology papers (Table 1). For each of the delayed recognition papers represented in Table 1, the year of peak citation occurs 23-70 years after publication. It is relevant to note that the year of peak citation is post-2000 for all nine papers, and for four papers the peak citation year is 2015 (Horton, 1945; King, 1953; Schumm 1956; Strahler, 1952b), the last year of this analysis. These four papers still show increasing citation rate with time and their true citation peaks may be in the future, which speaks to the continued relevance of these works. Note that the papers in Table 1 did not remain entirely uncited prior to their citation peak, but show a pronounced lack of citations directly after publication relative to their recent citation rates (Figure 2).

Rank	Title	Authors	Pub Yr	Peak Cit. Yr	B	t_a
1	DYNAMIC BASIS OF GEOMORPHOLOGY	STRAHLER, AN	1952	2008	384	1997
2	HYPSOMETRIC (AREA-ALTITUDE) ANALYSIS OF EROSIONAL TOPOGRAPHY	STRAHLER, AN	1952	2015	353	2001
3	EROSIONAL DEVELOPMENT OF STREAMS AND THEIR DRAINAGE BASINS - HYDROPHYSICAL APPROACH TO QUANTITATIVE MORPHOLOGY	HORTON, RE	1945	2015	344	1988
4	CONCEPT OF THE GRADED RIVER	MACKIN, JH	1948	2008	220	1993
6	CLASSIFICATION OF PATTERNED GROUND AND REVIEW OF SUGGESTED ORIGINS	WASHBURN, AL	1956	2003	180	2000
7	EVOLUTION OF DRAINAGE SYSTEMS AND SLOPES IN BADLANDS AT PERTH-AMBOY, NEW-JERSEY	SCHUMM, SA	1956	2015	179	2003
13	RIVER MEANDERS	LEOPOLD, LB; WOLMAN, MG	1960	2012	107	2001
15	CANONS OF LANDSCAPE EVOLUTION	KING, LC	1953	2015	103	2005
16	CHANNEL CHANGES IN BADLANDS	HOWARD, AD; KERBY, G	1983	2006	102	1998

Table 1: Nine geomorphology papers with a high delayed recognition score (B) in GSA Bulletin (1945-2016). Publication year, the year of maximum citations, and the awakening time (t_a) are also listed.

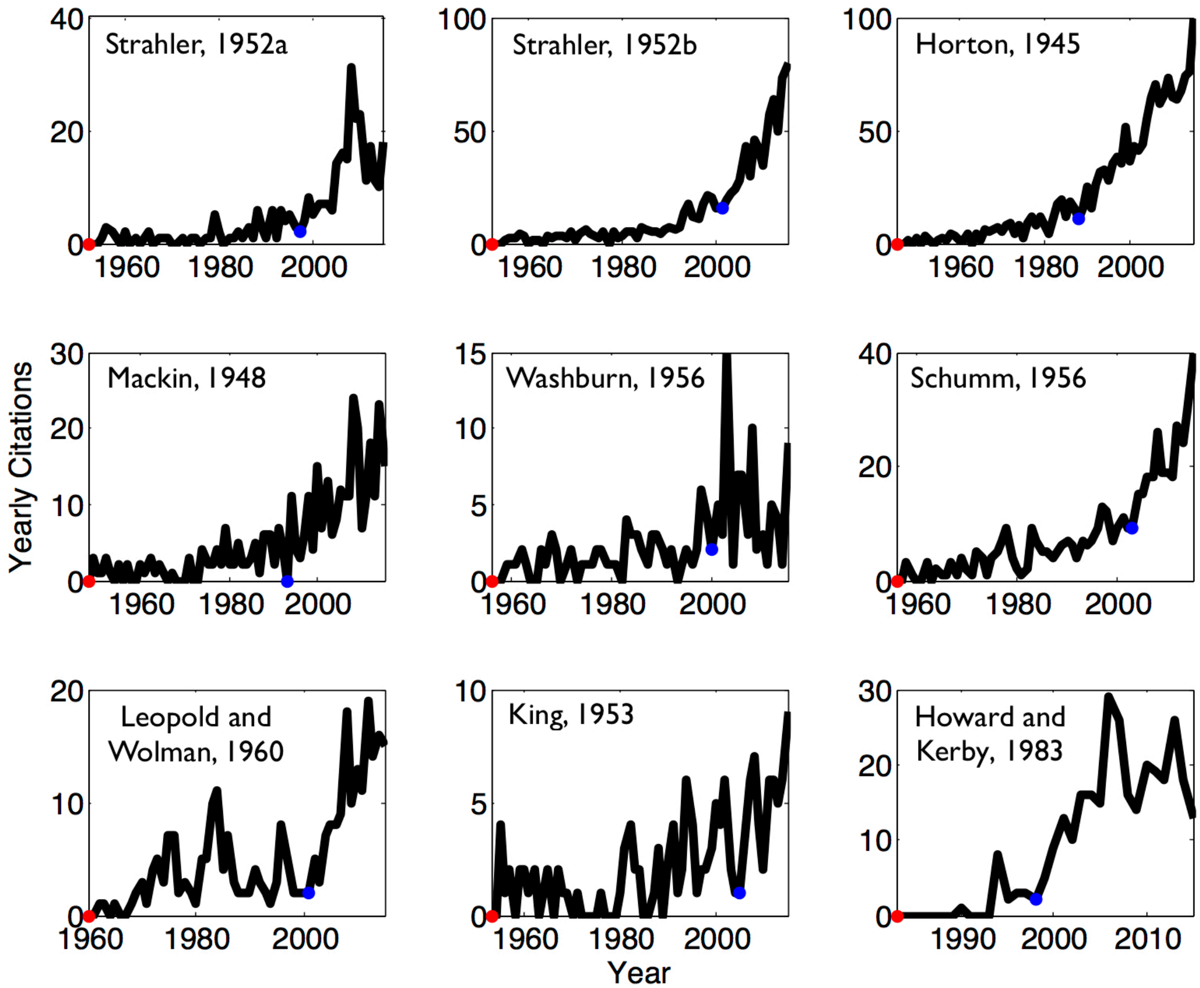

Figure 2: Yearly citation time series for the 9 papers in Table 1. Red dots indicate the date of publication. Blue dots indicate the awakening time (t_a). Note the difference in X and Y axis on each panel.

III. Discussion and Interpretations

These nine geomorphology papers with delayed recognition are not uniformly the most cited of GSA Bulletin articles. The papers in Table 1 range from the 2nd most cited paper in GSA Bulletin (Horton, 1945) to the 300th most cited (King, 1953). Only three of the 20 most cited GSA Bulletin articles are geomorphology. This quantitatively reinforces the fact that GSA Bulletin is a general geoscience journal— which makes the emergence of the nine articles in Table 1 anomalous. As others have suggested before, geomorphology might be prone to generate papers with delayed gratification as a result of the increase in quantitative geomorphology research in the past 20 years, aided by new tools and techniques (e.g., Church 2010; Wohl et al., 2016). It is clear from looking at the awakening time for all nine articles, which all fall within the range of 1988-2005, that there was a collective explosion of geomorphology research around this time. Intensive research in geomorphology also coincided with the adoption of the Internet — data from the World Bank on Internet users suggests that >50% of the US, Canada and UK population were internet users by 2002 (http://data.worldbank.org/indicator/IT.NET.USER.P2, accessed on March 6, 2017). The development and use of online academic search tools may have generally played a role in the increasing citations of older literature.

The importance of many of the papers in Table 1 has not gone unnoticed, and retrospective pieces have been written about nearly all of the papers. Morisawa (1988) discussed the importance of early quantitative geomorphology research in GSA Bulletin, specifically focusing on Horton (1945), Mackin (1948) and Strahler (1952a). Three papers from Table 1 have been chronicled in 'Classics Revisited' previously — Chorley (2000) on Mackin (1948), Ollier (1995) on King (1953), and Chorley (1995) on Horton (1945). Additionally, King (1953) is the subject of a retrospective by Twidale (2003), and Rhoads (2006) uses Strahler (1952a) as a lens for examining the philosophy of geomorphology. Even Strahler (1992) wrote in these pages on the historic narrative of his research program, which encompasses the two GSA Bulletin papers.

The specific reason why recognition has been delayed may be aided by examining the record of citations to each paper (what papers cited the delayed work) and also co-citations — instances where the paper with delayed recognition and another work are both cited in a third paper. Papers that are co-cited with the delayed paper may provide insight into why a given delayed paper was recognized. Furthermore, co-cited papers that were published around the awakening time, t_a also might be clues as to why a specific paper was 'awakened'. All co-citation analysis was performed with Web of Science data, the R programming language (R Core Team, 2016), and the R package bibliometrix (Aria and Cuccurullo, 2016).

It is likely that Washburn (1956) became highly cited as a result of the burst in activity surrounding patterned ground in the early 2000s — notable examples are Kessler et al. (2001) then Kessler and Werner (2003) who developed a self-organized model of patterned ground formation. Mackin (1948) has been valuable for a range of people and subsequent increases in citations to his work from the 1980s onward have been found from stratigraphy papers to landscape evolution papers to tectonic geomorphology works. Strahler (1952b), Horton (1945), and Schumm (1956) all show awakening times around the boom in research focused on tectonic geomorphology, bedrock rivers, and the modeling of landscape evolution. Horton (1945) is also extensively cited with works regarding the fractal nature of river basins (e.g., Rodríguez-Iturbe and Rinaldo, 2001) and channel initiation studies (e.g., Montgomery and Dietrich, 1992). The acquisition of high resolution topography and the personal computer revolution (which enabled the analysis of high resolution topography and various computer models) no doubt contribute to the interest in these landscape-scale research topics. For instance, Strahler (1952b) is often co-cited with Willgoose and Hancock (1998), a paper published around the awakening time of Strahler (1952b) that works to extend the utility of the hyposmetric curve using a landscape evolution model.

Howard and Kerby (1983) gives the clearest and most explainable trend in this dataset. The citation time series to this paper (Figure 1) shows a prominent uptick in citations in the late 1990s and early 2000s as a result in the explosion of interest in bedrock channels. Co-citations are dominated by bedrock channel literature dating from this time.

The awakening of some delayed papers is less clear— for example, I can find no reason that Strahler (1952a), which has the highest *B* value, became highly cited for a period of time. A book was published in 2008 (Burt et al., 2008) resulting in 8 citations to Strahler (1952a), but even without this book there is still a burst of citations. One plausible answer is that Strahler (1952a) is easy to return to — it clearly lays out a quantitative framework for the study of geomorphology (Morisawa, 1988). As a result, any new tool and technique can be brought to bear on these fundamental ideas and questions.

King (1953) is perhaps the outlier in these nine works. King's paper was notably qualitative, and even though two of King's 'Canons' are meant to spark quantitative and process based studies (Canon 49 and 50 on page 750; Twidale, 2003), as Ollier (1995) points out, he spoke warily of the mathematical treatment of geomorphology (King, 1953; p.746-747).

The geomorphology papers in Table 1 can be compared to delayed recognition in other disciplines. Redner (2005) gives examples of delayed recognition from the physics literature, noting that papers with delayed recognition from the American Physics Society database occur because of upsurges in interest regarding specific topics (e.g., Quantum Information) or novel measurement techniques (e.g., thin film transition metal oxides). Recent work by Ke et al., (2015) presented the most extreme examples of delayed recognition found among 22 million articles (the Web of Science and the American Physical Society records). None of these articles were from the geoscience literature, and most came from physics and chemistry. The B values of the papers from GSA Bulletin (B =384 to B =209) are 1-2 orders of magnitudes lower in B score than the fifteen most 'delayed' papers isolated by Ke et al. (2015), which vary from B =11,600 to B =2,184. Among many reasons for this disparity is the smaller size of the geoscience community, or perhaps the geoscience publication record may not be as large or diverse as other disciplines.

The papers in Table 1 serve as a reminder — in an age of exponentially increasing publications (Bornmann and Mutz, 2015) — of the value in searching through older literature during literature reviews (e.g., Pautasso, 2013), a task aided by the advent of online search tools. Ideas from older literature may now be testable or actionable because of new observation, new theory, or recent technological advances. Papers with delayed recognition remind us that good ideas might still be lying dormant in older literature.

Acknowledgement

I thank E. Janke, E. Lazarus and P. Limber for helpful discussions. I also thank the two anonymous reviewers, Editor David R. Butler, and Managing Editor Nicholas J. Clifford for comments on this work.

Declaration of conflicting interests

The author declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Funding

The author received no financial support for the research, authorship and/or publication of this article.

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